

Ni-coated Ti powders

The present invention relates to coated powder, comprising a Ti-bearing core and a Ni-bearing coating, which can be used for the production of porous Ni-Ti alloys.

Such a porous Ni-Ti alloy article is described in U.S. Pat. No. 5,986,169. The article has a porosity of 8 to 90 % and is defined by a network of interconnected passageways extending throughout. The network exhibits an isotropic permeability permitting complete migration of fluids. The material is elastically deformable. These characteristics render it useful in biomedical and other applications. For producing the porous article, the so-called self-propagating high-temperature synthesis (SHS) method is used in which the alloy is produced by means of a layered combustion which exploits exothermic heat emitted during interaction of elemental nickel and titanium powders.

U.S. Pat. No. 2,853,403 describes a method for producing composite metal powders. This method consists of dispersing, in solid form, particles of one or more metals of interest as nuclei in an ammoniated solution in which another metal of interest having different chemical and/or physical properties is present as a soluble salt, and precipitating the latter metal from the solution by gas reduction to form composite metal particles in which the dispersed metal particles are coated by the precipitated metal. This method was however never specifically applied for the manufacture of Ni-coated Ti powder.

The use of elemental Ni and Ti powders renders the production process sensitive to segregation problems, resulting in composition fluctuations and/or non-homogeneous porosity. Composition fluctuations can in turn lead to the formation of unwanted secondary phases.

According to the invention, the above drawbacks can be overcome using coated powder, comprising a metallic Ti-bearing core and a metallic Ni-bearing coating, characterised by a Ni:Ti atomic ratio of more than 0.5, preferably between 0.9 and 1.1, and more preferably between 0.96 and 1.04. Atomic ratios of more than 0.5 to about 1 are

preferred as this avoids the formation of secondary phases and yields an alloy with better mechanical properties.

5 The Ti-bearing core may consist of pure Ti, while the Ni-bearing coating can consist of pure Ni.

10 It may be useful to mix Ti-bearing powder or Ni-bearing powder with the coated powder so as to obtain a Ni:Ti atomic ratio of the mixture of between 0.9 and 1.1, and preferably between 0.99 and 1.01. This procedure allows for easy adjustments to the Ni:Ti ratio.

The particle size of the powders should preferably be finer than 150 mesh.

15 Above described powders can be used for the manufacture of sintered objects, possibly using the SHS technique.

Another object of the invention concerns a process of manufacturing a coated powder comprising the steps of:

- 20 - providing for suitable quantities of a Ti-bearing powder and of a Ni salt bearing aqueous solution;  
- feeding said powder and said solution in an autoclave together with a quantity of  $\text{NH}_4\text{OH}$ , and, optionally, with a quantity of ammonium salts;  
25 - precipitating the Ni onto the Ti-bearing powder by hydrogen reduction;  
- washing, filtering and drying the slurry obtained, thereby obtaining a Ni-coated Ti powder.

30 The Ni is preferably precipitated onto the Ti-bearing powder at a temperature of at least 100 °C and a hydrogen pressure in the autoclave of at least 1.4 MPa.

35 Powders obtained by this coating process are, as such or after mixing with Ni-bearing or Ti-bearing powders, suitable for SHS sintering of objects.

By using coated powders, local fluctuations in composition are limited and well under control. Ni-coated Ti powder also decreases  
40 the diffusion distance between the Ni and Ti atoms, which may

eliminate or reduce the formation of unwanted intermetallic compounds such as  $\text{Ni}_3\text{Ti}$  and  $\text{NiTi}_2$ . It has been found that the porosity of the porous titanium-nickel produced by SHS starting from Ni-coated Ti powder is more homogeneous throughout the sample compared to starting with elemental powders. It has also been found that the compactibility of Ni-coated Ti powder is significantly better than that of elemental powders. Because of this, next to the possibility for a decreased die wear, larger devices can be produced. Additional advantages are that no milling is required, thus avoiding contamination such as oxidation of Ti during the preparation stage, and that the intimate contact between Ni and Ti makes it possible to perform SHS with no or less preheating compared to green compacts made of elemental Ti and Ni powders.

The SHS process can produce Ni-Ti alloys with large pore volumes and a three-dimensional interconnected network of pores and channels. This porous network is particularly suitable for implants to achieve secure tissue-to-implant bonding. Pre-alloyed powder, such as atomised Ni-Ti, does not work for the SHS process, since it is already an alloy and the exothermic reaction does not take place during sintering.

During the manufacturing the coated powder, 50 to 500 g/l ammonium salts, such as  $(\text{NH}_4)_2\text{SO}_4$  or  $(\text{NH}_4)_2\text{CO}_3$ , may be added, to prevent the formation of unwanted  $\text{Ni}(\text{OH})_2$  and to ensures a smooth coating.

The following Figures illustrate the invention.

Figure 1 shows an SEM of coated product.

Figure 2 shows an EDS map of the cross section of Ni-coated Ti powder; the solid Ti cores (left) and the Ni-coating (right) are visible.

Figure 3 gives a longitudinal view of powder A after compaction and SHS; the arrow indicates the direction of the propagation front.

Figure 4 is a SEM-image of powder A (left) and powder B (right) after SHS.

Figure 5 shows an XRD spectrum of Ni-coated powder D after SHS.

Figure 6 shows macroscopic pictures of samples made by the SHS process using different raw materials: (a) using powder D, (b) powder E, (c) powder F, (d) powder G.

Figure 7 shows SEM pictures of samples made by SHS using various raw materials at low (top) and high (bottom) magnification: (a) and (d) for powder D, (b) and (e) for powder F, (c) and (f) for powder G.

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#### Preferred embodiment 1

Ti powder along with a Ni bearing solution, such as a sulphate or a carbonate, and, in particular when a sulphate is used, ammonium hydroxide (ammoniac), preferably in a  $\text{NH}_3:\text{Ni}$  ratio of 2:1, are fed to an autoclave. A surface-active additive, such as anthraquinone, is also added to the solution to an amount of 0.2 to 5 wt.% of the Ti powder. This ensures a smooth coating of the Ti particles. The Ni is then precipitated on the titanium surface using  $\text{H}_2$  at a temperature of 100 to 200 °C and at an  $\text{H}_2$  pressure of 1.4 to 3.4 MPa. After coating, the slurry is washed, filtered and dried.

#### Example 1

The result of coating a batch of Ti powder as described in preferred embodiment 1 is given in Table 1. The reduction temperature was 150 °C and the reduction pressure was maintained at 3.4 MPa. A SEM (Scanning Electron Microscope) picture of the coated product is shown in Figure 1. An EDS (Energy Dispersive Spectroscopy) map of the cross section of the powder is shown in Figure 2. SEM and EDS maps show a homogeneous and smooth coating.

Table 1: Results of coating

Feed		Coated powder	
Ni (g/L)	Ti (g/L)	Ni wt. %	Ti wt. %
21.8	21.6	53.2	46.6

#### Example 2

Ni-coated Ti powder was produced starting from 3 types of Ti powder having a different particle size distribution:

- powder A: Ni coated -400 mesh Ti powder;
- powder B: Ni coated -250 +325 mesh Ti powder;
- powder C: Ni coated -150 +200 mesh Ti powder.

The composition of the coated powder is shown in Table 2.

Table 2: Composition of the coated powder

Powder reference	Composition	
	Ni wt. %	Ti wt. %
A	53.8	45.8
B	53.7	46.1
C	53.3	46.0

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### Example 3

The three different powders were die-compacted on an Instron-press to a density of respectively 48 %, 59 % and 51 % of the theoretical density using a compaction load of 22 kN, 19 kN and 11 kN respectively.

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SHS performed on compacted powder A requires an ignition time of less than 10 seconds. The propagation front is parallel and stable and the resulting sample dimensions are also stable (Figure 3). Powders B and C showed a tendency to more intensive melting in the upper part of the sample.

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Two types of pores are present: small ones and large elongated ones perpendicular to the propagation front direction (Figure 4). As the initial particle size increases from powder A to powder C, the width of the elongated pores increases from roughly 200-300  $\mu\text{m}$  to 400-600  $\mu\text{m}$  and finally to 800-1000  $\mu\text{m}$ . The porosity distribution in each sample is homogeneous, except in the regions where a large amount of liquid phase was present, resulting in lower porosity.

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The phases present in the SHS-product have been determined using XRD (X-Ray Diffraction) and EDX (Energy Dispersive X-ray) analysis. The XRD diagram in Figure 5 clearly shows the presence of the desired Ni-Ti phase, both monoclinic and cubic, and possibly a limited amount of  $\text{NiTi}_2$ .

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Example 4

To be able to compare Ni-coated Ti powder with elemental Ni and Ti powders, the following batches were prepared:

- powder D: Ni coated -400 mesh Ti powder, blended with some additional Ni powder;
- powder E: Ni coated -250 +325 mesh Ti powder, blended with some additional Ni powder;
- powder F: Ni coated -150 +200 mesh Ti powder, blended with some additional Ni powder;
- powder G: Ni powder of 1.2  $\mu\text{m}$  ( $d_{50}$ ), mixed with -250 +325 mesh Ti powder in a 1:1 atomic ratio (55.07:44.93 Ni:Ti wt.% ratio).

Based on the composition analysis of the Ni-coated Ti powder, additional fine Ni powder was blended with the coated powder to balance the Ni:Ti atomic ratio to 1:1. The addition of Ni powder is shown in Table 3.

Table 3: Amount of Ni added to 100 g of Ni-coated Ti powder

Powder reference	Ni:Ti (wt.%)	Ni powder added (g)
D	53.8:45.8	2.34
E	53.7:46.1	2.80
F	53.3:46.0	3.08

- Quartz tubes with a diameter of 20 to 25 mm and a length of 130 to 170 mm were used for containing the powder. Powder mixture G was ball milled for 2 hours before being loosely packed in a quartz tube. Green density of the mixed powder was about 50 to 60 %. A load of 30 to 40 kN was needed to press the sample.
- The green densities for powders D, E and F were respectively about 45%, 50% and 65%, accomplished using loads of 10 kN, 15 kN and 18 kN respectively.

All samples were placed in a vacuum chamber with a vacuum of about 0.01 Pa. After pre-heating the samples to 350 °C for 1 hour, the samples were ignited. SHS took place.

Figure 6 shows macroscopic pictures of the samples prepared by SHS. The surface morphology of the samples made by Ni-coated Ti powder was

homogeneous. The surface morphology of the samples made by mixed Ni and Ti powders was rough and the porosity was inhomogeneous.

- 5 SEM pictures in Figures 7(c) and 7(f) show that the pore size and morphology of the sample made from mixed Ni and Ti powder are inhomogeneous. Figures 7(a), 7(b), 7(d), and 7(e) show that the pore size and morphology prepared from finer Ni-coated Ti powders are more homogeneous than those by coarser Ni-coated Ti powder. There are also more open pores in the samples using finer Ni-coated Ti powders.
- 10 Overall, samples using Ni-coated Ti powder have a more homogeneous porosity than that using mixed Ni and Ti powders.